Introduction to Panel Surveys in Transportation Studies
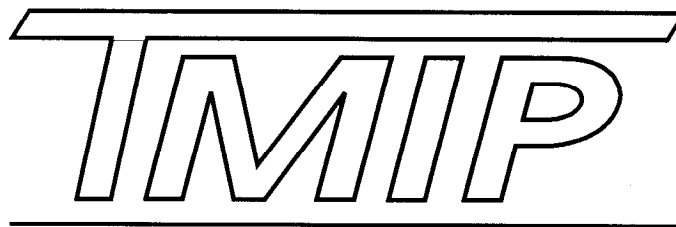
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Travel Model Improvement Program

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AN INTRODUCTION TO PANEL SURVEYS IN TRANSPORTATION STUDIES

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Travel Model Improvement Program

The Department of Transportation, in cooperation with the Environmental Protection Agency, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1.   To increase the ability of existing travel forecasting procedures to respond to emerging issues including: environmental concerns, growth managements, and lifestyles along with traditional transportation issues,

2.   To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3.   To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decisionmakers in state governments, local governments, transit agencies, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

Introduction to Panel Surveys in Transportation Studies

October 1997

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1.
EXECUTIVE SUMMARY

This report is a general introduction to the use of panel designs in surveys of travel behavior. It has four main objectives:

▸ to highlight the differences between cross-sectional and panel approaches to the study of travel behavior,

▸ to discuss the limitations of cross-sectional and panel data,

▸ to identify situations where panel data are preferable, and

▸ to provide guidelines for designing and maintaining a panel survey.

The report contains a number of recommendations concerning the conduct and use of panel designs in travel surveys. They are summarized below.

GUIDELINES FOR CONSIDERING A PANEL DESIGN

Consider using a panel design whenever the purpose of the travel survey is:

▸ to develop travel demand models and forecast future demand,

▸ to measure and understand trends in population behavior,

▸ to assess the impact of a change in transport policy or services, or

▸ to collect timely information on emerging travel issues.

GUIDELINES FOR DESIGNING AND CONDUCTING A PANEL SURVEY

▸ Use the household as the sampling unit and follow initial respondents as they move to new households.

▸ Collect data from respondents once a year unless more frequent data are required to meet the objectives of the survey.

▸ Add a supplemental sample of households to improve the representativeness of the panel if the composition of the population in the study area undergoes substantial changes during the survey period, or if the survey continues for five or more years.

- ▶ To reduce panel attrition, maintain contact with respondents between waves, develop a locating protocol for tracing respondents who move, give respondents small cash incentives in advance of their participation, and drop only hardcore refusals from the panel.

- ▶ Add new modules to the survey instruments as new issues arise, but change the core instruments only when absolutely necessary.

- ▶ Weight the data to produce unbiased estimates of population behavior.

2.

INTRODUCTION

Over the past few decades, several hundred travel surveys have been conducted within the United States, mostly by regional transit agencies and metropolitan planning organizations [1]. The data from these surveys have been used for such diverse purposes as measuring the impact of changes in the transportation system on travel behavior, forecasting future travel patterns and demand, and developing marketing campaigns to promote transit use. Nearly all the surveys have relied on cross-sectional designs that measure variation in travel behavior among the members of a population.

The purpose of this report is to discuss a different kind of survey design that measures variation in travel behavior at the level of the individual household or person by taking repeated measurements on the same sample of units at different points in time. These designs, referred to as *panel* or *longitudinal designs* in the survey literature, provide direct information on how the travel behavior of individual households or persons changes over time in response to other factors.

Although panel designs have enjoyed widespread use in transportation studies in other countries, and in work in other fields, they have rarely been adopted in travel surveys in the United States. This report shows how they can be used to address a variety of transportation policy and planning issues, ranging from impact assessments of specific policy changes on travel behavior to the more general issues of predicting and planning for future trends in behavior.

The report begins by describing the differences between panel and cross-sectional approaches to the study of travel behavior. It then discusses the advantages and limitations of these approaches to data collection, identifies situations where panel data are desirable, and illustrates their benefits through examples drawn from the transportation literature. The final section of the report provides guidelines for the conduct of panel surveys, focusing on the special issues and difficulties that arise when the same sample of households or individuals is measured repeatedly over time.

2.1. CROSS-SECTIONAL AND PANEL DESIGNS

All surveys can be classified into one of two broad categories on the basis of whether they obtain repeated measurements on the same sample of units over time. Panel surveys do and cross-sectional surveys do not.

Within these two approaches to data collection, surveys may be further distinguished according to whether they monitor changes in the population over time. Cross-sectional and panel surveys that incorporate this feature periodically

draw new samples from the population and collect measurements on them using the same methods as in previous time periods.

The differences among these four approaches to the collection of survey data are summarized in Table 1. The table distinguishes between two types of cross-sectional designs—*one-time cross-sectional designs*, and *repeated cross-sectional designs*—and two types of panel designs—*longitudinal panel designs,* and *rotating* or *revolving panel designs*. It shows how the designs differ along four dimensions:

► the number of distinct samples in the survey,

► the number of time points or measurement periods,

► the number of measurements per sample member, and

► the types of differences measured.

Table 1
Differences Among the Features of Four Types of Survey Designs

Approach	Design	Number of Distinct Samples	Number of Time Points	Number of Measurements Per Sample Member	Type of Variation Measured		
					Variation Among Sample Members (Cross-sectional Variation)	Variation Within Sample Members Across Time (Longitudinal Variation)	Variation in the Population Across Time
Cross-sectional	One-time cross-sectional designs	one	one	one	Yes	No	No
Cross-sectional	Repeated cross-sectional designs	two or more (same as the number of time points)	two or more	one	Yes	No	Yes
Panel (Longitudinal)	Longitudinal panel designs	one	two or more	two or more (same as the number of time points)	Yes	Yes	No
Panel (Longitudinal)	Rotating panel designs	two or more	two or more	two or more (generally less than the number of time points)	Yes	Yes	Yes

comparable conditions. But, unlike repeated cross-sectional designs, they ask the questions of the same sample members and thus provide for direct measurement of individual change.

During the first wave of data collection, longitudinal panel surveys provide the same information as one-time cross-sectional designs. They assess current population levels and measure cross-sectional variation in travel behavior. During the second and subsequent waves, longitudinal panel surveys also measure cross-sectional variation, but they may not measure current population levels since the composition of the current population may no longer be the same as it was in the first wave when the sample was drawn. However, if the time span of the survey is relatively short and the panel sample is periodically refreshed, chances are high that data obtained in each wave will reflect current population levels.

Revolving or rotating panel designs. *Rotating* or *revolving panel* surveys are a combination of repeated cross-sectional and panel designs. They collect panel data on the same sample of units for some specified number of measurement periods. Portions of the sample are then gradually dropped from the panel and replaced with new but comparable samples drawn from the current population. The process of retiring portions of the existing sample and adding new members to the sample continues until the original panel is completely replaced. The new sample members are retained in the survey for some specified number of measurement periods and then gradually replaced with a comparable but more current sample and so on. The survey may continue indefinitely or be limited to a certain number of replacement samples. Each sample of units selected at the same time and adhering to the same schedule of data collection is called a rotation group.

The strength of rotating panel designs lies in their ability to allow for short-term analysis of individual or household change and long-term analysis of population and subgroup change. As in panel surveys consisting of a single sample of the population, rotating panel designs provide direct information on change at the level of the individual household or person over the period in which the sample member is retained in the survey. As in repeated cross-sectional designs, they provide information on how travel behavior changes over time at the population or other aggregate levels by periodically drawing comparable samples from the current population and obtaining similar measurements on them.

Other variations. Although most surveys fall into one of these four categories, there are many variations within each category not discussed here. For example, it is possible to have a rotating panel design in which portions of a sample are retired from the survey for some specified number of time periods and then returned to the survey for additional measurement periods.

3.
CROSS-SECTIONAL VS. LONGITUDINAL DATA
FOR SURVEYS ON TRAVEL BEHAVIOR

3.1 USES OF PANEL AND CROSS-SECTIONAL DATA

The most obvious and important benefit of panel surveys is that they directly measure behavioral change at the level of the individual sample member and thus supply information that cannot be obtained in a cross-sectional survey. By virtue of this feature, they provide a rich source of information that can be used to arrive at a better understanding of the factors that influence and control personal travel behavior. This information is important whenever the purpose of the travel survey is:

► to develop travel demand models and forecast future demand (e.g., to develop models of transit mode share and to predict transit mode share following the introduction of a new rail line),

► to measure and understand trends in population behavior (e.g., to measure change in the average household trip rate and understand why the rate has changed or remained constant),

► to conduct behavioral analyses (e.g., to determine fare or travel time elasticity), or

► to assess the impact of a change in transport policy or a change in the transportation system (e.g., to measure changes in travel behavior following the opening of a new rail line) [2].

The sections below discuss why panel designs are preferable in these situations.

DEVELOPING TRAVEL DEMAND MODELS AND FORECASTING FUTURE DEMAND

Although cross-sectional data are well suited for assessing current levels of travel and for measuring period trends in population behavior, they provide only *indirect* information on the determinants of personal travel behavior. Nonetheless, this information, in the form of differences across households or individuals, forms the basis for most predictive models of personal travel behavior. These models assume that household or individual changes in personal travel behavior can be predicted on the basis of cross-sectional differences in behavior across households or persons [3]. Since these models are based on data from a single point in time, they are often referred to as "static" models in the literature. (Models based on panel data are typically referred to as "dynamic" models, on the other hand.)

For illustrative purposes, suppose one wanted to predict how the automobile trip frequency of a one-car household would change if it acquired an additional automobile. In models relying on cross-sectional data, this change in trip

frequency would be predicted on the basis of the difference in trip frequencies between one- and two-car households.

This type of inference assumes that several restrictive conditions are met:

▶ the changes are instantaneous,

▶ the changes are the same in either direction, and

▶ the relationship among variables is stable or invariant over time [3].

In terms of the example above this means:

▶ the acquisition of the additional automobile and the change in trip frequency occur simultaneously,

▶ a reversal—a change back to one automobile—returns the household to its previous travel rate, that is, the same frequency of trips as before, and

▶ the relationship among the number of automobiles and trip frequency remains the same over time.

Recent studies challenge the validity of these assumptions and the suitability of cross-sectional data for predicting changes in travel behavior. A study based on data from the Dutch National Mobility Panel (DNMP), for example, offers empirical evidence that changes in trip frequency and employment status do not occur simultaneously, as assumed in cross-sectional models [4]. In the study, sample members were divided into four groups according to their employment status in the first and second waves of the survey: employed - employed; employed - not employed; not employed - employed; and not employed - not employed. Analysis of changes in trip frequencies within these groups revealed strong inertia effects; trip frequencies did not change very much regardless of changes in employment. The average trip rate of male adults in the "not employed - employed" group, for example, was smaller than the sample average by 0.9 trips in the first wave, and remained smaller than the sample average by 0.7 trips in the second wave. The average rate of male adults in the "employed - employed" group, on the other hand, was greater than the sample average by 0.7 trips in the first wave, and 0.9 trips in the second wave. In other words, trip rate changes from the first to second wave were about equal for both groups. These results suggest that changes in employment status do not immediately produce a drop or gain in trip frequency as assumed in models of cross-sectional data.

A simple example that compares regression coefficients from static and dynamic models of travel behavior also illustrates how the predictions of travel demand models may be affected when they are based on cross-sectional versus panel data [5]. For the example, a static model was fit to the cross-sectional data from a panel survey

conducted in South Yorkshire, England, between 1981 and 1984. A dynamic model (a model based on individual changes over time) was fit to the panel data from the same survey. The regression coefficients from both models are shown in Table 2.

Table 2

The Effect of Income on Three Travel-Related Measures in the South Yorkshire Panel, 1981-1984

Measure/ Time Period	Regression Coefficients and their (Standard Errors)		Dynamic
	Static		
	1981	1984	1981-1984
Total Trip Rate	0.065 (0.01)	0.110 (0.02)	0.072(0.02)
Bus Trip Rate	n.s.*	n.s*	0.021 (0.01)
Car Ownership	0.043 (0.003)	0.054 (0.004)	n.s.*

*the coefficient was non-significant

The dynamic coefficient from the regression of changes in total trip rate on changes in income is within the range of the two static coefficients. The static coefficients, however, differ from one another and show that the assumption of stability does not hold in these data. Moreover, the panel results for bus usage and car ownership are quite different from the cross-sectional results. The model based on cross-sectional data predicts no change in bus usage and an increase in car ownership as income increases. The model based on panel data, on the other hand, predicts an increase in bus usage and no change in car ownership with changes in income.

The panel results for income and bus usage seem out of line with results from other studies and with what one would expect to find. However, a plausible explanation for the finding lies in the relationship among income, bus usage, and employment status within the group of panel members who typically travel to work by bus. Within this group, changes in employment status are likely to produce rather marked increases or decreases in bus usage and income, depending on the direction of the change in employment status. If such changes in status occur between the waves of data collection, then the data from this group would exhibit a relatively strong relationship between changes in income and changes in bus usage. When combined with data from the other panel members—whose income and bus usage may be changing in other ways—these changes could produce a small effect of income on bus usage, such as that observed in this survey.

MEASURING AND UNDERSTANDING TRENDS IN POPULATION BEHAVIOR

Repeated cross-sectional designs yield measurements of period trends in population behavior, but they do not further our understanding of why the changes occur. Panel designs yield similar information but also allow for analysis of the underlying causes by providing information on the changes occurring to individual members of the population. Aggregate measures of change tend to mask these changes and often lead to erroneous conclusions of stability, even when the behavior of the individuals is volatile.

Cross-sectional data from the South Yorkshire Panel Survey of car ownership, for example, show modest increases in net car ownership, ranging from about 2 to 6 percent during each time interval (see Table 3) [5]. The panel data, on the other hand, indicate that ownership levels were quite volatile during this time period. Between 21 and 26 percent of the population changed their level of ownership during each time interval. Moveover, between 13 and 15 percent acquired additional automobiles, while about 7 to 12 percent reduced their level of ownership. Since these changes differ in direction, they tend to cancel one another out when measurements are based on cross-sectional data. For this and other reasons, aggregate measures of change tend to provide an inaccurate picture of changes occurring to members of the population.

Table 3

Changes in Car Ownership of the South Yorkshire Panel

Changes in Level of Car Ownership	Time Interval			
	1981-1984	1984-1986	1986-1988	1988-1991
Ownership Reductions	10.5%	8.6%	7.2%	11.6%
No Change	76.4%	78.5%	79.1%	73.7%
Ownership Increases	12.8%	12.9%	13.6%	14.6%
Net Increase in Car Ownership	2.3%	4.3%	6.4%	3.0%

CONDUCTING BEHAVIORAL ANALYSIS

Cross-sectional surveys provide sufficient data for examining travel behavior at a single point in time and for analyzing and modeling differences in travel behavior across individuals, but they reveal very little about the dynamics of personal travel behavior. Cross-sectional data, for example, show that public transportation usage is negatively correlated with automobile ownership, but they can not predict

how much an individual's usage might change following a change in car ownership. Data from six waves of the DNMP illustrate this point [5]. Static correlations between public transport usage and car ownership are in the order of -0.20 suggesting that an increase in car ownership will lead to a moderate decrease in use of public transit. The dynamic correlations are in the order of -0.05 showing that changes in car ownership have little effect on an individual's use of public transportation.

IMPACT ASSESSMENTS

Before-and-after designs are commonly used in transportation surveys to study the impact of transport services and policy on travel behavior, attitudes, and safety. In studies of this type, the phenomenon of interest is measured before and after a change in services or policy to assess the impact of the change. Examples of such studies include:

► assessments of the impact of new legislation on travel behavior (e.g., reduction in trip frequencies following the passage of telecommuting laws),

► evaluations of the effects of improvements to the transportation system (e.g., reductions in fatality and injury rates following the construction of roadside barriers), and

► examinations of the impact of new technologies on traffic flow patterns and attitudes (e.g., changes in travel behavior and attitudes following the introduction of changeable message signs or Advanced Traveler Information Systems).

In one such survey conducted in Almere, Netherlands sample members were asked to report their mode of transportation to the workplace, along with other information—such as car availability—before and after the opening of a new railway line [6, 7]. In a similar study conducted in San Diego, sample members were asked to report their travel behavior and attitudes before and two times after a roadway for high-occupancy vehicles was opened on Interstate 15. The second and third waves of data were used to evaluate short- and long-term effects of the roadway on personal travel behavior [8].

In assessments of this type, the advantages of a panel design are clear. In comparison to a repeated cross-sectional design, a panel design:

► requires a smaller sample size to measure change over time,

► costs substantially less if the number of time points is relatively small, and

► permits examination of individual differences in the direction and magnitude of change.

To illustrate the type of information that would be lost if a repeated cross-sectional survey was adopted instead, data from the Almere study are shown in Tables 4 and 5. Table 4 displays the type of aggregate-level information that would be obtained in a repeated cross-sectional design and in a panel design. It shows the number and percent of sample members who traveled to work by car, train, or bus before and after the opening of the new railway line. According to these data, the level of travel by car remained the same across time, while bus use substantially declined after the opening of the railway.

Table 4

Mode of Transportation to the Workplace Before and After the Opening of the Rail Line

Mode Choice	Before		After	
	Number	Percent	Number	Percent
Car	320	67.4%	321	67.6%
Train	—	—	119	25.1%
Bus	155	32.6%	35	7.4%

The data in Table 5, available only in a panel survey, provide a more complete picture of the effects of the railway line on travel patterns. Of the 320 individuals who originally traveled to work by car, 27 or (about 8 percent) switched to train while 5 (or roughly 2 percent) switched to bus. But, more surprisingly, 33 (or roughly 21 percent) individuals who originally traveled to work by bus chose to drive to work after the opening of the line. Without the benefit of a panel design, these turnovers in mode use would be missed.

Table 5

Change in Mode of Transportation

Mode Choice Before	Mode Choice After					
	Car		Train		Bus	
	Number	Percent	Number	Percent	Number	Percent
Car	288	90.8%	27	8.4%	5	1.6%
Bus	33	21.3%	92	59.4%	30	19.3%

3.2 OTHER ADVANTAGES OF PANEL DESIGNS

In addition to providing for direct measurement of change, panel surveys offer a number of other practical and analytical benefits. These benefits include:

► increased statistical efficiency,

► timely information about emerging travel issues, and

► reduced cost relative to cross-sectional surveys.

Statistical efficiency. When the same sample of units is used in all time periods, estimates of change over time become more precise. This is because in panel surveys comparisons across time periods are free from some of the effects of random sampling error. As a result, panel surveys require a smaller sample size than repeated cross-sectional surveys to measure aggregate change with the same level of precision. For simple statistics like averages or proportions, the reduction in sample size depends on the correlation over time in the variable of interest (for example, the number of cars available to the household).

If R is the correlation between the measurements of a variable over time, then the variance of the estimate of change (the difference between measurements at time 1 and time 2) is reduced by a factor of $1-R$, while the standard error of the estimate is reduced by a factor of $\sqrt{1-R}$ [9]. This means that separate cross-sectional samples of size n_c, where

$$n_c = n_p \times \frac{1}{\sqrt{1-R}} \; ,$$

are required to measure change with the same level of precision as that provided by a panel sample of size n_p.

In cases where the correlation between measurements is high, the gains in efficiency can be quite large. Kish, for example, reports the results of a survey on car ownership in which the measurements correlate 0.8 over time [10]. In this case, the variance of the difference between the measurements is reduced by a factor of 0.20, the standard error by a factor of $\sqrt{0.20}$. In terms of the formula above, this means that the cross-sectional samples must be $1/\sqrt{0.20}$ or roughly 2.24 times larger than the panel sample to yield estimates of equal precision as measured by their standard errors.

$$n_c = n_p \times \frac{1}{\sqrt{1 - 0.20}} = n_p \times 2.24$$

Timely source of travel information. Once a panel survey is in place, it can serve as an ongoing source of up-to-date information about travel behavior. New data can be examined as they become available, and questions can be added to the survey instrument as needed to address current concerns and policy issues. It is often far easier and faster to add supplemental questions in an existing panel than to mount a whole new survey to acquire the same information. The extent to which a panel survey will serve this purpose should be decided in advance of the survey since it may affect the content and length of the core questionnaire.

Cost savings. Because panel surveys measure the same sample across time periods, sampling and respondent recruitment costs are considerably lower than those for repeated cross-sectional designs, where a new sample must be drawn and recruited during each time period. In later waves, these savings may be offset somewhat by the extra effort required to "feed and maintain" a panel sample. However, if the design includes only a few waves, a panel survey should cost considerably less than a repeated cross-sectional survey with the same number of measurement periods. The savings include some or all of the instrument development and pretesting costs, the costs of screening and recruiting the initial sample, and much of the costs of developing systems for monitoring the field effort and processing the data. Depending on the exact design, the costs of reinterviewing a panel may be 20 to 80 percent less than the costs of obtaining the same information from a new sample. Lawton and Pas estimate that the cost per sample household in subsequent waves of a travel panel survey is about 50 percent of the cost in the first wave [11].

3.3 SPECIAL PROBLEMS WITH PANEL DESIGNS

If panel surveys have advantages over cross-sectional designs, they also have certain drawbacks [12]. These include:

▸ *panel attrition*, or nonresponse in later waves of data collection;

▸ *time-in-sample effects,* or the effect of prior reporting on reporting in subsequent waves of data collection [13];

▸ *seam effects*, or an apparent increase in the number of changes across rounds of a survey as compared to the number observed within each round [14].

In a panel survey, the effects of nonresponse in the initial wave of data collection are compounded over time as initial respondents drop out in subsequent waves. The cumulating impact of nonresponse across waves of data collection is called panel attrition. As panel attrition increases, the sample becomes less and less representative of the cohort it was selected to represent.

To illustrate the cumulative effects of nonresponse, Table 6 shows the number of respondents who participated in each of the first four waves of the Puget Sound Transportation Panel (PSTP). About 33 percent of eligible members in the original sample took part in the first wave of data collection. Only about 55 percent of those original respondents completed the fourth wave of data collection in 1993. In other words, only 18 percent of the original sample of eligible members remained in the survey after the fourth round of data collection.

Table 6

Number of Respondents and Percent of Original Sample in the First Four Waves of the Puget Sound Transportation Panel

Year	1989	1990	1992	1993
Wave	1	2	3	4
Number of Respondents	1,713	1,385	1,080	935
Percent of original panel	—	81%	63%	55%

Similar information for the Dutch National Mobility Panel is shown is Table 7. After the first year of data collection, which consisted of two waves, the DNMP retained about 58 percent of the original respondents. By the end of the survey, only about one third of the original respondents remained in the panel.

Table 7

Number of Respondents and Percent of Original Sample in Selected Waves of the Dutch National Mobility Panel

Year	1984	1985	1986	1987	1988	1989
Wave	1	3	5	7	9	10
Number of Respondents	1,764	1,031	853	668	629	576
Percent of original panel	—	58%	46%	38%	36%	33%

Reporting errors can also increase among those who remain in the panel over time. There are several terms for such time-in-sample effects, including *conditioning* [15], *rotation bias* [16], and *panel fatigue* [14]. All three terms refer to the same general phenomenon: respondents tend to report fewer trips, spells of unemployment, household repairs, and consumer purchases in the later rounds of a panel survey than in the earlier ones.

This pattern of reporting is evident in data from the DNMP [17]. According to a regression model fit to those data, participants in the first wave reported about 2.27 fewer trips per week than expected, while participants in the seventh wave reported about 8.35 fewer trips per week than expected. Table 8 shows how the magnitude of underreporting increased over time as participants completed more rounds.

Table 8

Estimated Number of Unreported Trips Per Week by Wave

Wave	1	2	3	4	5	6	7
Number of Trips	2.27	4.44	5.70	6.60	7.20	7.87	8.35

In some cases, a drop in reporting can be observed within a single round; for example, respondents tend to report more consumer purchases in the first few days of keeping a diary than in the last few days, even in the initial wave of a panel survey. A number of studies have examined whether respondents in travel surveys display this pattern of reporting as they complete multi-day diaries. The results of the studies are mixed. Analysis of 1984 data from the seven-day travel diary of the Dutch National Mobility Panel, for example, revealed that trip reporting decreased over time largely because more respondents reported no trips at all over time [18]. Analysis of data from a three-day travel survey conducted in Seattle in 1989, on the other hand, found no evidence of decreased levels of diary reporting in the second and third days [19].

Another kind of reporting error may affect panel surveys that collect information about the entire period between rounds of data collection. In such surveys, respondents might be asked to report the amount they earned in each month since the prior interview. In these types of designs, there is a tendency for respondents to report changes as occurring at the beginning or end of the time interval between rounds rather than at other times covered by the interview. Changes in salary, for example, seem to cluster in the first month covered by the interview. This pattern of reporting is called the *seam* effect; it reflects the effect of faulty memory for when changes took place [14].

In summary, then, panel designs can compound the problems of nonresponse bias and reporting errors that are also found in cross-sectional surveys.

4.
ISSUES IN CONDUCTING
A PANEL SURVEY

4.1   OVERVIEW

There are numerous choices that must be made during the design and implementation of a panel survey. These include such basic issues as:

- the definition of the sampling unit (households, addresses, or persons),

- the choice of a sample size,

- the addition of cases to the sample to maintain the size of the sample, its representativeness, or both,

- the number and spacing of rounds of data collection,

- the method (or combination of methods) to be used in collecting the data,

- the tracing of households and individuals who move between rounds,

- the use of incentives, and

- the use of other techniques to reduce attrition.

Current practice. To help frame our discussion of these issues, Table 9 presents the relevant features of two general-purpose travel panels and two other prominent panel surveys on labor force behavior. These successful panel surveys illustrate some of the common solutions to the problems raised in planning and carrying out longitudinal studies.

Table 9

Comparison of Methods Used in Four Panel Surveys

Survey Name	Puget Sound Transportation Panel (PSTP)	Dutch National Mobility Panel (DNMP)	Current Population Survey (CPS)	National Longitudinal Survey of Youth (NLSY)
Frequency of Data Collection	Annually or bi-annually	Twice a year	Every month on a rotational basis of 4-8-4 months.	Annually 1979-1994; biannually thereafter
Unit	Household	Household	Housing units	Individuals and, in some cases, their children
Length of Interval	Approx. one or two years	March & September b/w March 1984 & March 1989	A month	B/w 1979 and 1994, 1 year; from 1995 on, 2 years
Use of Incentives	$2 bill, attached to each set of diaries, for each person who completes diaries	None	None	Through 1994 $10.00; thereafter $20.00
Follow-up postcards, etc.	Holiday greeting postcard, summary report, letter before renewal	None	None	None
Data Collection Method	Phone survey & 2-day travel diary	A 7-day travel diary	Face-to-face and telephone interview, supplementary done by mail survey	Face-to-face interview supplemental data collected via self-administered questionnaire

**Paper-and-pencil personal interview*
**Computer-assisted personal interview.*
***Self-administered questionnaire.*

4.2   DESIGN ISSUES

DEFINITION OF THE SAMPLE UNIT

With any study design, it is necessary to specify a sampling unit. Most personal travel surveys use households as their sampling units.[1] The PSTP and the DNMP follow this convention [21,22]. Other possible units for travel panels include persons or housing units.

The issues surrounding the definition of the sample unit can get a little complicated when the study involves a panel design. The complication arises because the units may change over time and one must decide which units to keep in the panel.

When the sampling unit is a person, as in the National Longitudinal Survey of Youth (NLSY), it is usually clear whether or not to retain the individual in the panel. Generally, persons who leave the population (for example, by moving out of the study area or by becoming institutionalized) are dropped from the sample, but all others are retained. With both households and housing units, however, things are not so straightforward. Households can divide because of divorce or for other reasons. One member may leave the household and join a different one. New members may be born into a sample household or may join it by marriage or adoption. The sample design must include rules for dealing with each of these situations. A common strategy is to collect data from all persons in any household that includes at least one respondent from the first round of the survey (provided that these persons meet the other eligibility criteria for the study, such as living in the study area). For example, if a household in one wave consisted of a couple that subsequently splits up, then in later waves both of the resulting households would be included in the sample. Similarly, if a new member joins a sample household, then data are collected from that new member. (However, if that new member subsequently leaves, he or she would not be followed unless his or her new unit includes a respondent from the first round of the survey.) This strategy entails following respondents who move out of their original household into a new one and collecting data on the other members of the new household. The process of following respondents and collecting data on their households can get a

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[1] Households are generally defined as groups of people who live together in a single dwelling or housing unit. In most definitions, group quarters, such as dormitories and nursing homes, do not qualify as housing units. According to the U.S. Bureau of the Census, a housing unit is a house, apartment, mobile home, group of rooms, or single room with separate kitchen facilities and with direct access from the outside of the building or through a common hall. To qualify as a housing unit, the occupants must live and eat separately from other persons in the building. A family, one person living alone, and other groups of related or unrelated persons who share such living arrangements qualify as households.[20].

little complicated when the original panel includes households shared by single persons since splits and new combinations are especially common in this group.[2]

It is also possible for housing units to subdivide over time into two or more units. (For example, an apartment may be remodeled into two units.) Again, each new unit formed from the units in the original sample should be included in later waves of the survey. This strategy is followed in the Current Population Survey (CPS), which uses a sample consisting of housing units [23].

CHOOSING A SAMPLING UNIT

Recommendation	*Use the household as the sampling unit for panel surveys. Follow initial respondents to new households and add any additional household members to the panel.*

THE NUMBER AND SPACING OF ROUNDS

Another set of design issues concerns the number and spacing of the rounds or waves of data collection. The best spacing will depend on such factors as the rate of change in the phenomena of interest and the need for up-to-date information. For example, the more rapidly travel demand is changing, then the more frequently data should be collected. Another consideration is the need for timely figures for administrative or other reporting purposes. The CPS is conducted every month in order to meet the need for monthly figures on the unemployment rate.

Another consideration affecting the spacing between rounds is the memory burden imposed by the data collection. Some panel surveys collect a continuous record for the entire period between rounds. In each new round of the NLSY, for instance, respondents are asked to report their employment history for the entire period between the current and preceding round of data collection [24]. In such cases, it is important to keep the spacing between rounds relatively short to reduce the impact of forgetting on the accuracy of the data. The effect of the spacing of rounds on memory burden does not appear to be a consideration in either the PSTP or the DNMP; in both of these travel panels, the main data collection instrument is a multi-day travel diary that covers only a short period preceding each round.

The DNMP used a six-month interval between waves of data collection. The PSTP uses a one-year interval (although the PSTP collected some additional

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[2] When a sample is drawn from areas with high rental costs or large numbers of students, such as San Francisco or Washington, D.C., the number of splits and new combinations is likely to be high since these areas tend to include a high percentage of single persons living together in households.

attitudinal data between waves of travel data collection) [21,22]; similarly, the NLSY has used a one-year spacing between rounds for most of its life [24].

Taken together, the spacing of the waves and the total life of the panel determine the total level of burden on the respondents. It is unreasonable to expect sample members to provide accurate information during many waves of data collection over a very long period of time. Instead, panel members are likely to drop out and the quality of the information they provide is likely to decline as the number of rounds increases. A rotation design can help limit reporting burden on each member of the sample. The CPS uses a scheme in which sample members participate for four months, are given eight months off, and then participate for four additional months [23]. The other illustrative surveys in Table 9 do not use rotation designs. The NLSY is now entering its 18th round of data collection and the PSTP is beginning its 10th round. The DNMP came to an end in March of 1989, after 12 rounds of data collection.

COLLECT DATA ONCE A YEAR

Recommendation

Conduct waves of data collection once a year unless more frequent data collecting is required to obtain the desired information.

METHOD OF DATA COLLECTION

The method used to collect data is another key design decision. Different methods of data collection differ in terms of cost, coverage of the population, likely response rates, and data quality. Data quality is usually measured in terms of the rates of missing or inconsistent information. In general, in-person data collection is the most expensive, but produces the most complete coverage and highest response rates; in addition, it affords greater opportunities for aids to the respondent. Telephone data collection tends to be next most expensive, but omits the portion of the population without telephones.[3] Telephone data collection also yields lower response rates than in-person data collection. Data quality may suffer somewhat as compared to data collected in a face-to-face interview. Finally, data collection by mail is the cheapest of the three modes; it offers, in principle, coverage similar to that of in-person data collection, but a lower response rate and poorer data quality. (When the questions are sensitive, however, a mail questionnaire may yield more accurate answers because respondents need not worry about an interviewer's reaction.) These points are summarized in Table 10.

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[3]The rate of omission from telephone surveys is higher for the unemployed (12 percent of whom live in households without telephones) young adults (16 percent of those between the ages of 15 and 24 live in households without telephones), and poor households (more than 20 percent of households with annual incomes of less than $5,000 lack telephones) than for their employed, older and wealthier counterparts.

Table 10

Mode of Data Collection and Their Features

	Mode of Data Collection		
	In-Person	**Telephone**	**Mail**
Description	Interviewer travels to respondent's home or office and administers questions in face-to-face interview	Interviewer contacts respondent and administers questions over the telephone	Questionnaire mailed to respondent and is returned by mail or data retrieved by telephone
Coverage	Most complete	Omits nontelephone households	Similar to in-person, depending on how the addresses are obtained
Response Rate	Highest of three modes	Intermediate	Lowest of three modes
Data Quality	Highest of three modes	Intermediate	Lowest of three modes
Cost	Most expensive	Intermediate	Least expensive

Most personal transportation surveys use a combination of telephone and mail data collection [1]. Telephone interviews are used to identify eligible households initially and to enlist their cooperation in the main data collection. Then, sample households are mailed a diary or some other data collection instrument. The data collection form may be mailed back by the respondents or the information recorded on it may be retrieved by telephone. Both the PSTP and the DNMP relied on some combination of mail and telephone to collect their travel data.

Recommendation	**UTILIZE MORE EXPENSIVE MODES IN THE INITIAL WAVE**
	In the first wave of the survey, contact respondents by telephone or in-person to maximize the initial response rate. Thereafter, adopt less expensive modes of data collection if necessary.

SAMPLE SIZE

Another key design decision concerns the choice of a sample size for the survey. The process of choosing a sample size usually consists of three steps:

► identifying the desired level of precision for the survey estimates,

► computing the size of the sample required to obtain estimates at that level, and

► adjusting the size to take into account nonresponse, attrition, and eligibility rates.

Setting the precision level. The process of choosing a sample size begins with an assessment of the amount of error that can be tolerated in the survey estimates. In the case of a panel survey, the assessment usually focuses on the estimates of change since they are of primary concern. The objective is to determine how precise the estimates must be to satisfy the goals of the survey. This determination requires information on the kinds of questions that will asked of the data and the types of analyses that will be performed. Once this information is obtained, then the precision level is set at the value that will meet the analysis goals of the survey. While it is possible to obtain estimates of even higher precision, the costs of doing so usually outweigh the benefits.

Calculating sample size. Once the target precision level is set, then the number of cases, n , required to reach that level can be estimated using standard formulas for sample size estimates [25]. The formulas applied in this step will depend on the sampling design of the survey. In any case, the formulas will require some information about the expected rarity, rate, and variability of changes in the variables of interest. When the statistical properties of the variables are expected to differ, a separate computation is usually performed for each critical variable (variables that are essential to accomplishing the goals of the survey) since the computations will, as a rule, yield different values of n. When the numbers are reasonably close in value, the largest n is typically selected if resources for the survey can support a sample of that size. When there is considerable variation among the numbers, the desired level of precision may be relaxed for some variables or some variables may be dropped from the survey if they can not be measured with an acceptable level of precision given the resources available.

Adjusting for attrition, nonresponse, and eligibility rates. In the final step of the process, estimated sample sizes are usually adjusted to take into account the effects of nonresponse, attrition, and rate of eligibility. Since nonresponse and attrition reduce the size of the sample, the number of units in the initial sample must be larger than the required n to yield a final sample of the desired size. The adjustment for these losses is made by dividing the estimated sample size by the product of the expected response rate for the first wave and the cumulative retention rate for the remaining waves. (The cumulative retention rate is the proportion of first wave respondents who go on to complete all waves.) In situations where the sampling frame includes units who are not eligible to participate in the survey, the sample size must also be adjusted by the expected eligibility rate, the proportion of sample units expected to qualify for inclusion in the study. In this case, estimated sample size is divided by the product of the response, retention, and eligibility rates to yield an estimate of the number of cases that must be drawn from the sampling frame to obtain a final sample of the desired size.

4.3 MAINTAINING THE PANEL

FRESHENING THE SAMPLE

Freshening the sample refers to adding units to the sample over time. It is done in order to represent new members of the population (such as households that moved into the study area after the original sample was selected), to compensate for losses from attrition, or both. In rotation group designs, the addition of new rotation groups in later rounds of the survey is a built-in feature of the design.

Adding new units to improve or maintain representativeness of the sample. New units may be added to the original sample in later rounds of data collection so that the sample accurately reflects changes in the population over time. In a transportation panel study, it may be important to represent households that are new to the study area (either because they are newly formed or because they have moved in from outside the study area)[4]. New units may be found by screening a cross-sectional sample of households. For example, a sample of telephone numbers may be selected and asked screening questions to determine whether the household could have been included in the initial sample.

The longer the panel study is continued, the less representative the panel will become of the current population. As a result, the decision about whether to incorporate new selections in later rounds is likely to depend in part on the expected life of the panel. When the panel continues for five or more years, inferences about the current population are likely to be inaccurate when they are based on the original sample.

Recommendation	*ADD CASES TO MAINTAIN REPRESENTATIVENESS* *If a panel continues for five or more years, or if there is substantial immigration to the study area, add a supplemental sample to cover new households not represented in the original sample.*

Adding new units to maintain sample size. In all panel surveys, a certain percentage of respondents drop out over time; thus, the cumulative retention rate will be less than 100 percent of the original sample in subsequent waves of data collection. To make up for this loss, some panel studies add new units to maintain a sample size adequate to support the required analyses. The Puget Sound Transportation Panel and the Dutch National Mobility Panel both introduced new units in later waves to maintain adequate sample sizes when respondents dropped out of the panel study [21,22]. The required sample size is

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[4] Newly formed households in the population will be represented to some degree by splits in the original sample, but these splits may not be representative of newly formed households in the current population.

typically determined at the beginning of the panel study and it must be maintained throughout the length of the study.

There are several alternatives to adding units in subsequent rounds. They include 1) maintaining a low rate of attrition; 2) planning the initial sample size to include an allowance for the expected rate of attrition over time, and 3) using a rotation group design, in which old cohorts are replaced by new ones after a certain period. Adding cases to replace nonrespondents raises difficult statistical issues for weighting the data. We recommend against this practice.

Recommendation	**ALLOW FOR ATTRITION IN PLANNING THE SIZE OF THE PANEL SAMPLE** To avoid having to add cases later on, the initial sample size should allow for losses due to attrition in later waves and the survey procedures should attempt to minimize attrition. Adding cases to replace nonrespondents should be done only as a last resort.

Adding new rotation groups. The main purpose of rotation group designs is to reduce the reporting burden on panel survey respondents. Asking the same respondents to supply information in every data collection period, especially if the waves are closely spaced (for example, every month, as with the CPS) and the survey is scheduled to last for an indefinite or multiyear period, may substantially increase the attrition rate, introducing biases and reducing the precision of sample estimates [23]. A rotation group design limits the participation of each member of the sample, while preserving the advantages of overlap in the sample from wave to wave. When a large number of rounds of data collection are planned, a rotation group design may represent a good combination of the features of a cross-sectional and panel survey.

MAINTAINING HIGH RESPONSE RATES ACROSS WAVES

A panel survey faces all the same obstacles to a high response rate as a cross-sectional study. Some sample members will be reluctant to participate; others will be difficult to contact or locate. Still others will refuse to participate unless the survey accommodates their special needs. Unless measures are taken to overcome these obstacles, initial response rates are likely to be low.[5]

A panel survey faces the additional issues of following households that move over time and maintaining cooperation across multiple rounds of data collection. Most panel studies use several techniques in an effort to minimize attrition, including:

► tracing movers,

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[5]Methods for reducing nonresponse are discussed in detail in the FHWA publication, "Nonresponse in Household Travel Surveys" [26].

► maintaining contact with sample members between rounds, and

► providing incentives for participation.

Tracing movers. Panel respondents may change residence between waves of data collection, and time and money are needed to locate such respondents. The NLSY uses an elaborate locating method to trace movers. First, a locating letter is sent four months prior to the next data collection period which asks respondents to send an address or telephone update if their addresses or phone numbers have changed. The envelope requests the post office to send address corrections rather than forwarding the letters. Thus, updated address information may be obtained either from the panel respondent or the post office. If no information is received, then it is assumed that there is no change in locating information.

Based on the response to the advance letter, the locating information is updated. Letters returned by the post office without a forwarding address are sent to a "locating shop[6], along with any information about the sample member, such as his or her social security number, locating information for friends and family, the work address, and so on.[7] The locating shop first attempts to locate respondents by checking one or more publicly available databases. If these electronic searches fail to produce an address, field staff begin by calling the previous telephone number in case a recording is left with information about the new number. Friends, family, and work may also be called to obtain new addresses and telephone numbers for sample members who have moved. Due to such an extensive tracing system NLSY had maintained an overall retention rate of 89% through 1994.

It is important to trace respondents who have moved or changed telephone numbers so that the panel study can maintain the required sample size and reduce attrition. Adopting a comprehensive locating procedure is essential to minimize nonresponse bias.

DEVELOP A LOCATING PROTOCOL

Recommendation	To reduce attrition, develop a locating protocol to track respondents who have moved since the last round of data collection.

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[6]Some survey organizations maintain in-house locating shops. These shops typically subscribe to one or more databases that contain relatively up-to-date addresses and other locating information. Many credit bureaus, such as Equifax, provide a similar service. For a fee, they will search their databases for addresses and other information.

[7]Locating information, such as the names, addresses, and telephone numbers of relatives and friends, is typically collected from the respondent during the initial interview after a modicum of trust has been established.

Maintaining contact with households between waves. The time frame between waves in panel surveys may vary from a month as in the CPS to a couple of years as in the NLSY. During the interval between consecutive interviews or waves, it is important to maintain contact with the respondents in a panel survey. The PSTP uses a number of methods, including follow-up postcards, summary reports mailed after each wave, and reminder letters sent out before each data collection period.

These techniques help keep the respondents interested in the study, give them a sense of its importance, and remind them about upcoming waves of data collection. In addition, they can yield updated information on the respondent's whereabouts.

	MAINTAIN CONTACT WITH RESPONDENTS BETWEEN WAVES
Recommendation	To maintain respondent interest and get updated locating information, send postcards, holiday greetings, and summaries of results to respondents between waves.

Providing incentives. To encourage participation, many surveys provide cash or gifts to respondents; such incentives may be especially useful in panel surveys, which must maintain cooperation across multiple rounds of data collection. During the PSTP data collection period, $2 bills were attached to the travel diaries for each person in the household who was asked to complete one [21]. During the 1980's, the NLSY gave $10.00 to each respondent; after 1994, the incentive was increased to $20.00. The literature on incentives in surveys indicates that they are probably most effective when they are in the form of cash. The amount given to each respondent should be enough to entice him or her to participate but not so large as to impose a burden on the survey budget. The survey literature suggests that small prepaid incentives are the most effective for achieving high response rates. Unfortunately, this conclusion is based almost entirely on data from cross-sectional surveys. The limited literature on incentives in panel studies is inconclusive about their effectiveness in maintaining high response rates.

	PROVIDE CASH INCENTIVES TO REDUCE NONRESPONSE
Recommendation	To reduce attrition, use small prepaid cash incentives

Retaining wave nonrespondents. To minimize the effects of attrition, it is important not to write off sample members who become nonrespondents after the initial wave. Many of these "wave nonrespondents" may be willing to participate in later rounds. If wave nonrespondents are kept in the sample and some are "converted" in later waves, the effects of attrition may not be cumulative. The fact that, say, 10% of the initial respondents do not take part in the second wave should not necessarily impose a ceiling on subsequent retention rates. (Retention

rates refer to the proportion of the first wave respondents who complete later waves of data collection.) Cases that could not be located in one wave may be found later on; cases that were too busy to take part in one round may have more time in the next. In any panel sample, there will be cases that insist on being dropped from the panel; it may make sense to simply write off such cases since chances of converting them are very low. But a substantial portion of wave nonresponse is due to temporary circumstances and wave nonrespondents should not be automatically dropped from the panel.

Recommendation

DROP ONLY HARDCORE REFUSALS FROM THE PANEL
Many cases who fail to participate in one wave of data collection will participate in later waves if given the chance. To reduce the effects of attrition, wave nonrespondents should not be automatically dropped from the panel.

MODIFYING THE QUESTIONNAIRES ACROSS ROUNDS

A defining feature of a panel design is the administration of the same items to a sample of respondents on several occasions over time. It is this feature of panel designs that permits the direct measurement of change in individual units. It would, therefore, seem logical that questionnaires and data collection instruments should be kept the same across each wave of a panel study. Any changes in appearance, content, or wording of the instruments, or in the data recording or coding procedures, could compromise the comparability of the data in the different waves.

Two considerations may, however, make it necessary to change the data collection instruments used in a panel survey. In the first place, new issues may arise and the panel sample may be the best means for collecting information about them. As we noted in Section 2, one of the virtues of a panel study is its ability to provide timely information about emerging issues. When new issues arise, it may make sense to add a module or supplement to the existing instruments. In effect, the panel sample can be used to collect cross-sectional data on the new topic. Although this strategy may not capitalize on all the strengths of a panel design, it can save time and money compared to selecting and interviewing a new cross-sectional sample. In addition, the data collected about the panel members in previous waves may enrich the analysis of the data collected in the new module. However, since adding questions to the instrument will increase the burden placed on the panel respondents, the number of new items should be kept to a minimum. In some cases, it may be better to conduct a separate survey than to jeopardize the success of an ongoing panel.

A second circumstance that can argue for change in a panel questionnaire involves problems with an item. When a question yields unreliable data in each wave, the estimates of change become doubly unreliable. For this reason, it is important even in panel surveys to rewrite poorly worded questions or questions that appear to yield suspect data for other reasons. Although replacing faulty questions or instruments interrupts the sequence of comparable measurements, it may be necessary if the measurements are to be interpretable at all. Fortunately, the likelihood of finding faulty items can be substantially reduced through pilot testing of the instruments in advance of the main survey. However, sometimes the problem with an item is not that it was poorly conceived in the first place, but that it becomes less and less meaningful over time. The CPS was recently overhauled for the first time since 1967. Over the intervening years, many items that were once perfectly sensible no longer yielded the required information.

When the core items—those repeated in each wave—must be modified, it is often useful to carry out a calibration experiment, in which the old and new questionnaires are administered to different portions of the sample. The results of the calibration study can help analysts disentangle the effects of changes in the instruments from true change in the respondents.

ADD NEW MODULES AS NEW ISSUES ARISE

Recommendation	Although changes to the core instruments in a panel should be kept to a minimum, as new issues arise, modules can be added to get timely data. If a core instrument needs to be overhauled, a calibration study should be done to determine the effect of the change.

5.
WEIGHTING PANEL DATA

Panel samples, like other survey samples, usually need to be weighted to produce unbiased population estimates. Weights are typically applied for three reasons:

▸ to account for differences in the selection probabilities of individual cases,

▸ to compensate for differences in response rates across subgroups, and

▸ to adjust for chance or systematic departures from the composition of the population.

In a panel survey, weights are often computed in two stages. First, a weight is developed for the initial wave following standard procedures for cross-sectional samples. Then, the weights from the initial wave are adjusted to produce longitudinal panel weights. The sections below provide an overview of the steps involved in the process. The procedures and computational formulas are discussed in detail in the Appendix.

5.1 WEIGHTS FOR THE INITIAL WAVE

Weights for the first wave of a panel survey are usually calculated in three steps. In the first step, each unit in the sample is assigned a base weight to compensate for differences in the selection probabilities of the individual units. In some cases, these differences arise by design. The PSTP, for example, deliberately oversampled transit users. As a result, transit users had a higher chance of selection into the sample than other sample members. In other cases, the differences in selection probabilities are a byproduct of the sampling process. In telephone surveys, for example, households with multiple telephone lines have a greater chance of selection into the sample than households with a single line. In either case, population statistics derived from the data will be biased unless they are appropriately weighted to adjust for unequal selection probabilities.

The second step adjusts the weights for differences in subgroup participation rates. In most surveys, certain groups of individuals tend to participate at lower rates than other groups. In transportation surveys, the underrepresented groups usually include the elderly, the less well-educated, urban dwellers, families with young children, and young adults. Such differences in participation rates can introduce nonresponse bias into the results. Weighting for nonresponse can help reduce those biases.

The third step compensates for differences between the composition of the sample and the composition of the population. These differences may occur purely by chance or because the sampling frame omits a portion of the population. Telephone surveys, for example, omit the portion of the population without telephones. Weighting the data to compensate for this omission helps reduce the bias in population estimates.

5.2 PANEL WEIGHTS

While calculating cross-sectional weights for the first wave is rather straightforward, calculating household-level longitudinal weights raises special problems because sample households can change over the life of the panel survey. For example, a household that initially consisted of a married couple may divorce, forming two "new" single-person households. There are several different ways to treat households that split up or that add new members over the course of the survey, and decisions about how to handle such changes affect the computation of longitudinal weights. Thus, an essential first step in weighting longitudinal data involves deciding how households will be defined for weighting purposes.

Another decision affecting the computation of the weights concerns the rules for defining *responding* and *nonresponding* households over time. In most panel surveys, households are classified as respondents if they participated in all rounds of data collection. However, in certain circumstances other definitions may be useful as well. Suppose, for example, an analyst wanted to compare data from the first and most recent rounds of data collection. In this case, it makes sense to classify households as respondents if they completed these two rounds of data collection. In many cases, it may be necessary to define responding households in more than one way to meet the analysis needs of the survey. In such situations, a separate set of weights is generated for each definition.

Once these definitional issues have been resolved, the calculation of longitudinal weights is straightforward, following the same basic steps as those used to calculate cross-sectional weights. The steps involved in this process are discussed in detail in the Appendix.

6.

SUMMARY

This report provided a general introduction to the use of panel designs in transportation surveys. Through examples drawn from the transportation literature, it illustrated how panel designs could be used to address a variety of transportation issues. The report identified several situations where panel designs are preferable, either because they provide information that cannot be obtained in cross-sectional designs or because they are more efficient than cross-sectional designs. It then discussed the special issues and problems that arise when the same group of individuals is followed over time. The final sections of the report provided guidelines for designing and maintaining a panel survey, and for preparing panel weights for analysis of the data.

APPENDIX

COMPUTING WEIGHTS IN PANEL SURVEYS

A.1 WEIGHTING DATA FROM THE INITIAL WAVE

Step 1: Compensating for differential selection probabilities. Typically, the initial or base weight (W_{1i}) for a case (e.g., a sample household) is calculated as the inverse of that case's selection probability (Pr_i):

$$W_{1i} = 1/Pr_i \quad .$$

All eligible selections—whether they went on to complete the survey or not—should receive a base weight. The selection probability (or sampling rate) is the proportion of the population selected for the study. If the sample is purchased from a vendor, the vendor should provide the selection probability for each of the sample telephone numbers. In a random-digit dial (RDD) survey, the sampling unit is a telephone number and the selection probability is the percentage of possible numbers within the study area that were actually selected for the sample.

In stratified sample designs, the population is first divided into subgroups called "strata" and separate samples are selected within each subgroup. Often different sampling probabilities are used within the different strata. For example, the study area might be divided into counties; if the telephone numbers linked to different counties were subject to different rates of sampling, then separate selection probabilities would have to be computed for each county. The PSTP sample, for example, consists of four geographic strata—King, Kitsap, Pierce, and Snohomish Counties [27].

In an RDD survey, this base weight should be adjusted to compensate for the fact that people in households with multiple telephones have more than one chance of being selected into the sample. The standard adjustment is quite simple; it is the base weight for household i divided by the number of distinct household telephone lines (t_i):

$$W_{1i}' = \frac{1}{Pr_{1i} \, t_i} \quad .$$

In a survey in which households are first screened and then subsampled for the main data collection, the base weight should reflect the selection probabilities at both phases of selection—selection into the screening sample and retention for the main sample:

$$W_{1i} = \frac{1}{Pr_{1i} \, Pr_{2i}} \quad ,$$

in which Pr_{1i} represents the case's probability of inclusion in the screening sample and Pr_{2i} is its probability of retention for the main sample. If all eligible households are retained for the main data collection, then Pr_{2i} is one.

Step 2: Compensating for nonresponse. The base weight for the initial wave (W_1 or W_1 ') should then be adjusted to compensate for the effects of nonresponse. Nonresponse adjustments ensure that the sum of the weights is unaffected by nonresponse; they do this by reallocating the weights originally assigned to nonrespondents to the respondents. In addition, the nonresponse adjustments can reduce the bias introduced by nonresponse by compensating for differences in nonresponse rates across subgroups of the sample.

Nonresponse adjustments are often calculated by grouping cases into nonresponse adjustment cells and finding the (weighted) response rate for cases in that cell. In a travel survey, household size or number of vehicles might be used to form the nonresponse cells if that information is available for nonrespondents as well as respondents. For each cell, the weighted response rate R_j is:

$$R_j = \frac{\sum_{1}^{n_{rj}} W_{1ij}}{\sum_{1}^{n_{cj}} W_{1ij}} \quad ,$$

in which the numerator is the sum of the weights for the respondents in cell j and the denominator is the sum of the weights for all eligible cases in that cell.

The adjusted weight (W_2) is the base weight divided by the nonresponse adjustment:

$$W_{2ij} = \frac{W_{1ij}}{R_j} \quad .$$

For nonrespondents and ineligible cases, the adjusted weight is set to zero. The sum of the *adjusted* weights for the respondents in cell j should equal the sum of the *base* weights for the eligible cases in that cell.

Ideally, adjustment cells should be formed using variables that are related both to the likelihood of nonresponse and to the substantive variables of interest in the survey (such as travel behavior). Often, however, the choices are quite limited because so little is known about the nonrespondents and because both respondents

and nonrespondents must be classified into adjustment cells. For example, in a telephone survey, the only information available for the nonrespondents may be their area codes and exchanges (and any geographic information that can be inferred from these). Thus, the nonresponse adjustment cells have to be formed using whatever information happens to be available for the nonrespondents.

When there are two phases of data collection—a screening phase and a main interview phase—separate nonresponse adjustments should be calculated for each phase. The same adjustment cells need not be used in both phases. In fact, the screening data are generally useful for forming adjustment cells to compensate for nonresponse to the main interview. If R_{1j} denotes the weighted response rate in the first phase of data collection and R_{2k} the response rate in the second phase, then the adjusted weight would be:

$$W_{2ijk} = \frac{W_{1ijk}}{R_{1j} R_{2k}} .$$

The factors in the denominator of this equation (R_{1j} and R_{2k}) represent estimates of the probability that a given case will take part in the study. It is possible to derive these estimates from the observed response rate within a subgroup of the sample, but it is also possible to derive them through more sophisticated estimation procedures. Estimates of the response probabilities can be obtained via logit or probit models that take into account multiple characteristics of the sample members. Probit models were used to estimates response probabilities in the PSTP sample, and these estimated response probabilities were used, in turn, to adjust the PSTP weights [27].

Step 3: Post-stratifying to population estimates. If the weights have been properly calculated, their sum represents an estimate of the size of the population from which the sample was drawn.

Sometimes independent estimates of the size of the population are available (for example, from decennial census data). The weights can then be adjusted to bring the sums into agreement with those outside population figures. This method—called *post-stratification*—is used to correct for two types of errors in survey estimates—random sampling error and coverage error. Random sampling error refers to chance departures of the sample from the population it is selected to represent. Post-stratification can be expected to reduce random sampling error when the population estimate is derived from the decennial census or from a survey with a much larger sample than the one in the survey being weighted. Coverage error refers to systematic problems in who is included or excluded from the sample. Post-stratification can be expected to reduce the effects of coverage error when the population estimate gives better coverage of the population than

the travel survey sample does. For example, if a telephone survey was used to collect the data, the sample will necessarily exclude households without telephones. The two most commonly used sources of figures for post-stratification are the decennial census and the Current Population Survey; these are thought to achieve much higher levels of coverage of the general population than other surveys. The PSTP weights, for example, were adjusted to agree with the Public Use Microdata Set (PUMS), an extract from the decennial census data [27].

Post-stratification involves comparing the sum of the weights (i.e., W_2) for a given subgroup with the population estimate for that group. For example, the PSTP weights were adjusted to agree with the PUMS totals for income-household size-number of vehicle groupings within each county. The post-stratification adjustment is calculated by multiplying the current weight for cases in a subgroup, say subgroup j, by the ratio between the population estimate for that subgroup

(N_j) and the sum of the weights for sample cases in that subgroup:

$$W_{3ij} = W_{2ij} \frac{N_j}{\Sigma W_{2ij}} .$$

The adjustment cells are typically defined in terms of areas (such as townships) and one or more demographic variables (such as household size).

Population figures for poststratification adjustments (the values for N_j in the equation) can be obtained from decennial census data, the CPS, or other Census Bureau estimates. Which source to use will depend on how recent the data are, whether they are based on sufficient sample sizes (in the case of the CPS), and whether they provide appropriate grouping variables.

In general, both household-level and person-level weights can be calculated. Both sets of weights can incorporate nonresponse and post-stratification adjustments (and different adjustment cells can be used in developing weights for households and persons).

A.2 DEVELOPING PANEL WEIGHTS

Step 1: Defining longitudinal households for weighting purposes. One practical approach to defining longitudinal households is to continue to treat as a household all the persons who made up the household at the time of the first wave of data collection, regardless of what other changes that household subsequently undergoes. That is, each household is a treated a collection of persons and the longitudinal weight is applied to this collection of persons even if they no longer live together. For instance, if a couple divorced after the initial wave of data

collection, the longitudinal household weight would still be attached to both of the households they now form. (Of course, analysts might want to take into account that this "household" now encompasses two separate residences, each of which may include other persons.) Although this approach has some obvious drawbacks, it is preferable to the main alternatives discussed in the statistical literature (for example, restricting the analysis to intact households) and we recommend that it be adopted in travel panel surveys.

Step 2: Developing longitudinal base weights. Having defined longitudinal households, the next step in creating a longitudinal weight is to calculate a base weight, reflecting the household's selection probability. Generally, the households retained for follow-up in subsequent waves of the panel are drawn from the sample of responding households in the first wave. Sometimes all Wave 1 respondents are included in the sample for Wave 2; in other cases, only a subsample is retained for follow-up. When the sample for later waves is drawn from Wave 1 respondents, the base panel weight (W_{p1}) can be computed by dividing the final Wave 1 household weight by the probability of retention for later waves:

$$W_{1i} = \frac{W_{3i}}{Pr_{ri}}$$

Since this initial weight is based on the final Wave 1 weight, it incorporates corrections for Wave 1 nonresponse and adjusts for any discrepancies between the composition of the Wave 1 subsample and the population from which it was drawn. If *all* Wave 1 respondents are retained for follow-up, the initial panel weight is simply the final Wave 1 weight.

If new units are added to the sample in later waves, they must also receive a panel weight. If the new households represent in-movers (that is, immigration to the study area) or other additions to the Wave 1 population (e.g., births, returns from an institution), then the procedures outlined for weighting the Wave 1 households apply to the households added in later rounds as well. The new cases represent a new component of the population, one that was not previously eligible for inclusion in the sample.

When the new households are added because of changes in the composition of Wave 1 households, the situation is more complicated. Members of sampled households in the initial wave of a panel survey are sometimes referred to as "key" members of the sample. Other persons who join the households of key members after the initial wave but who were part of eligible population at the time of the first wave of the study are referred to as "non-key" members of the sample.

Our recommended definition of a longitudinal household implies that data should be collected for key members in subsequent waves even if they move out of the household that was sampled initially. For weighting purposes, these persons remain linked to their Wave 1 households. However, data should also be collected for non-key members while they are part of a household containing a key member; the data for non-key members can be used understand the context of the responses of the key members [28].

All key members of the sample constitute the core sample for *person-level* analyses, both cross-sectional and longitudinal. Non-key members are included in person-level analyses only in those waves when they were members of a household that included a key member of the panel survey. An alternative to the above methodology is to include *only* key members in all person-level analyses as done in the National Medical Expenditure Survey (NMES) [28].

Step 3: Compensating for nonresponse. Once a longitudinal household has been defined for weighting purposes, it is necessary to develop rules for classifying the household as a panel respondent or nonrespondent. The simplest rule is to classify a household as a panel respondent if it provides the necessary data in each wave. For example, in a three-wave survey, households would be classified as respondents if they completed data collection in all three waves. All other households would be treated as nonrespondents. The base weights of the responding households can then be adjusted by the weighted response rate (that is, the weighted proportion of households that completed all three waves of data collection):

$$W_{2ij} = \frac{W_{1i}}{R_j} \ .$$

This definition of respondents would produce a single set of longitudinal weights for all three waves. However, the definition may be too stringent for some purposes. For example, an analyst may be interested only in data from the initial and most recent waves of data collection. For that purpose, it may be useful to treat households that completed those two waves of data collection as respondents, even if they failed to take part in some intervening wave. This definition would produce a set of pairwise weights for the first and most recent waves. Pairwise weights for the second and third waves could be generated in the same way.

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GLOSSARY OF TERMS

ADJUSTED WEIGHTS: See nonresponse weighting.

CALIBRATION EXPERIMENT: When old and new versions of a survey instrument are administered to different portions of the sample to assess the impact of changes in the questions on responses.

COHORT: A group of individuals within a population who have experienced the same life event during some specified period in time. Cohort is usually defined by year or period of birth, but it may be used to refer to the timing of any number of other life events, such as year of retirement or year of marriage.

CONDITIONING: See time-in-sample effects.

CPS: Current Population Survey.

DNMP: Dutch National Mobility Panel.

FIELD PERIOD: The time period during which survey data are collected from the respondents.

HOUSEHOLD: The U.S. Bureau of the Census defines a household as all persons who occupy the same housing unit. A household may consist of a family, one person living alone, two or more families living together, or any other group of related or unrelated persons who share living arrangements.

HOUSING UNIT: The U.S. Bureau of the Census defines a housing unit as a house, apartment, mobile home, group of rooms, or single room that is occupied (or if vacant, is intended for occupancy) as separate living quarters. To qualify as a housing unit, the occupants must live and eat separately from any other persons in the building and have direct access from the outside of the building or through a common hall.

INCENTIVE: A monetary or nonmonetary gift or payment offered to sample members in an effort to gain their cooperation.

LOCATING LETTER: A letter sent by mail to the respondents in advance of the next data collection period in an effort to obtain updated addresses and telephone numbers before the next round of data collection.

LONGITUDINAL WEIGHTS: Weights designed to be used in longitudinal analyses of data from a panel survey.

LONGITUDINAL PANEL DESIGNS: Designs that collect information on the same set of variables from the same sample members at two or more points in time.

MODULE: An independent part of a questionnaire that covers a single subject or topic of interest.

NLSY: National Longitudinal Survey of Youth.

NMES: National Medical Expenditure Survey.

NONRESPONSE: Failure of the survey to obtain the desired information from eligible sample members.

NONRESPONSE WEIGHTING: Postsampling statistical adjustment to partially compensate for possible nonresponse error. Statistical weighting to compensate for nonresponse is different from the postsampling weighting that is routinely performed to adjust for unequal probabilities of selection.

ONE-TIME CROSS-SECTIONAL DESIGNS: Designs in which sample members are asked to complete a survey once.

PANEL ATTRITION: Failure of first-wave respondents to complete the survey in subsequent rounds of a panel survey.

PANEL DESIGNS: Designs that collect repeated measurements on the same sample of individuals or households over time.

PANEL FATIGUE: See time-in-sample effects.

POST-STRATIFICATION: When weights are adjusted to agree with independent population estimates. Post-stratification compensates for deviations between the distribution of characteristics in the sample and the target population.

PSTP: Puget Sound Transportation Panel.

REPEATED CROSS-SECTIONAL DESIGN: Designs that collect measurements on a population over time by repeating the same survey on two or more occasions. During each time period, a separate but comparable sample of units is drawn from the population.

RESPONSE RATE: A measure of a survey's level of success in obtaining the desired measurements from all eligible units in the sample; the number of respondents divided by the total number of eligible units in the sample.

RETENTION RATES: The proportion of respondents from the first wave who complete later waves of data collection in a panel survey.

ROTATION GROUP BIAS: See time-in-sample effects.

ROTATING PANEL DESIGNS (REVOLVING): A panel design that collects measurements on a sample for some specified number of periods after which the sample is dropped from the survey and replaced with a new but comparable sample of units drawn from the current population.

ROTATION GROUP: A sample of units drawn from the population at the same time and following the same schedule of data collection in a rotating panel design.

RDD: Random Digit Dialing. Techniques that form samples by adding random digits to the telephone prefixes that fall within the sampling area so as to include both listed (published) and unlisted numbers in the sample.

SAQ: Self-administered questionnaire. A questionnaire that is completed by the sample member without the assistance of an interviewer. Respondents to self-administered questionnaires are asked to read the questions and record the answers on their own.

**SAMPLING UNIT:** An element in a sampling frame from which a survey sample is drawn.

SEAM EFFECTS: Apparent increase in the number of changes across rounds of a survey as compared to the number observed within a round.

TIME SERIES DESIGN: A design that collects a series of repeated measurements over a relatively large number of points in time.

TIME-IN-SAMPLE EFFECTS: Effects of prior reporting on reporting in subsequent waves of data collection. Conditioning and fatigue refer to reduced levels of reporting across waves. Rotation bias refers to differences across rotation groups related to their time in the sample.

WAVE: A distinct occasion when data are collected in a panel survey. Also referred to as a round of data collection.

WEIGHTED RESPONSE RATE: A response rate that is calculated using the inverse of the selection probabilities as the weight. The weighted response rate is an estimate of the proportion of the target population represented by the respondents to the survey.
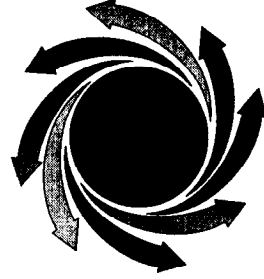
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